COMMISSIONING AND OPERATION OF AN ULTRAFAST ELECTRON DIFFRACTION FACILITY AS PART OF THE ATF-II UPGRADE AT BROOKHAVEN NATIONAL LABORATORY *

M.Fedurin†, M.Babzien, C.Folz, M.Fulkerson, K.Kusche, J. Li, R. Malone, M. Palmer, T. Shaftan, J. Skaritka, L. Snydstrup, C. Swinson, F. Willeke, Brookhaven National Laboratory, Upton, USA

Abstract

The Accelerator Test Facility (ATF) at Brookhaven National Laboratory (BNL) is presently carrying out an upgrade, ATF-II, which will provide significantly expanded experimental space and capabilities for its users. One of the new capabilities being integrated into the ATF-II program is an Ultrafast Electron Diffraction (UED) beam line, which was originally deployed in the BNL Source Development Laboratory. Inclusion of the UED in the ATF-II research portfolio will enable ongoing development and extension of the UED capabilities for use in materials research. We describe the design, operation and future plans for the UED beam line at the ATF-II.

INTRODUCTION

The Accelerator Test Facility at Brookhaven National Laboratory (BNL) is a US Department of Energy Office of Science National User Facility supported by the Accelerator Stewardship Program (ASP). The ASP mission is to *support fundamental accelerator science and technology R&D and disseminate accelerator knowledge and training*. In its role of support the ASP, the ATF provides its users with access to a high-brightness 80-MeV electron beam as well as a Terawatt-class picosecond CO_2 laser, which can be used individually or synchronized with the electron beam for combined experimental operation. The ATF-II upgrade of the facility aims to provide expanded capabilities for the accelerator research community [1]. One of the opportunities afforded by this upgrade has been to expand the ATF electron beam portfolio to include an Ultrafast Electron Diffraction (UED) facility, which was originally developed as part of the research effort at the BNL Source Development Laboratory [2]. By integrating this facility with the ATF-II complex in BNL Building 912, accelerator researchers will be able to continue to explore ways to advance and optimize accelerator technology for UED, and also the closely associated Ultrafast Electron Microscopy (UEM) applications for the materials science research community.

Fast diffraction measurements represent a key probe of structural dynamics in a range of materials. At present ultrafast experiments based on FEL x-ray sources and electron beams enable us to probe the relevant physical processes [3-4]. An advantage of electron beams is their large interaction cross-section. However, there are challenges associated with obtaining short pulses of sufficient charge to probe processes on femtosecond timescales in a single pulse due to the space charge effects which limit the minimum bunch lengths that can be obtained [5]. A key thrust of the planned UED research program will be to demonstrate techniques which optimize the time resolution of the device, targeting femtosecond-scale performance.

THE UPDATED UED FACILITY AT BROOKHAVEN

A formal decision to incorporate the UED facility into the ATF-II was made in November 2015. At that point, an aggressive implementation plan was put into effect which was executed with the following schedule:

- December 2015: Facility layout, as shown in Figure 1, was developed and approved. The detailed beam line layout is shown in Figure 2.
- January-February 2016: The accelerator and photocathode laser systems were deployed in BNL Building 912.

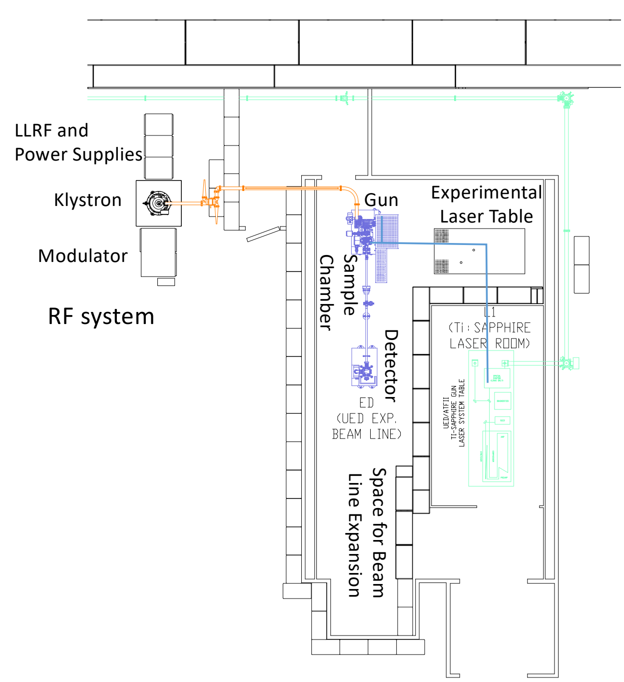

Figure 1: Layout of the UED Facility, which is housed in BNL Building 912 as part of the ATF-II expansion. A key feature is the space for beam line expansion which will enable future R&D work to optimize the parameters provided by the UED apparatus.

* Work supported by the US DOE under contract DE-SC0012704.
† fedurin@bnl.gov

Copyright © 2017 CC-BY-3.0 and by the respective authors

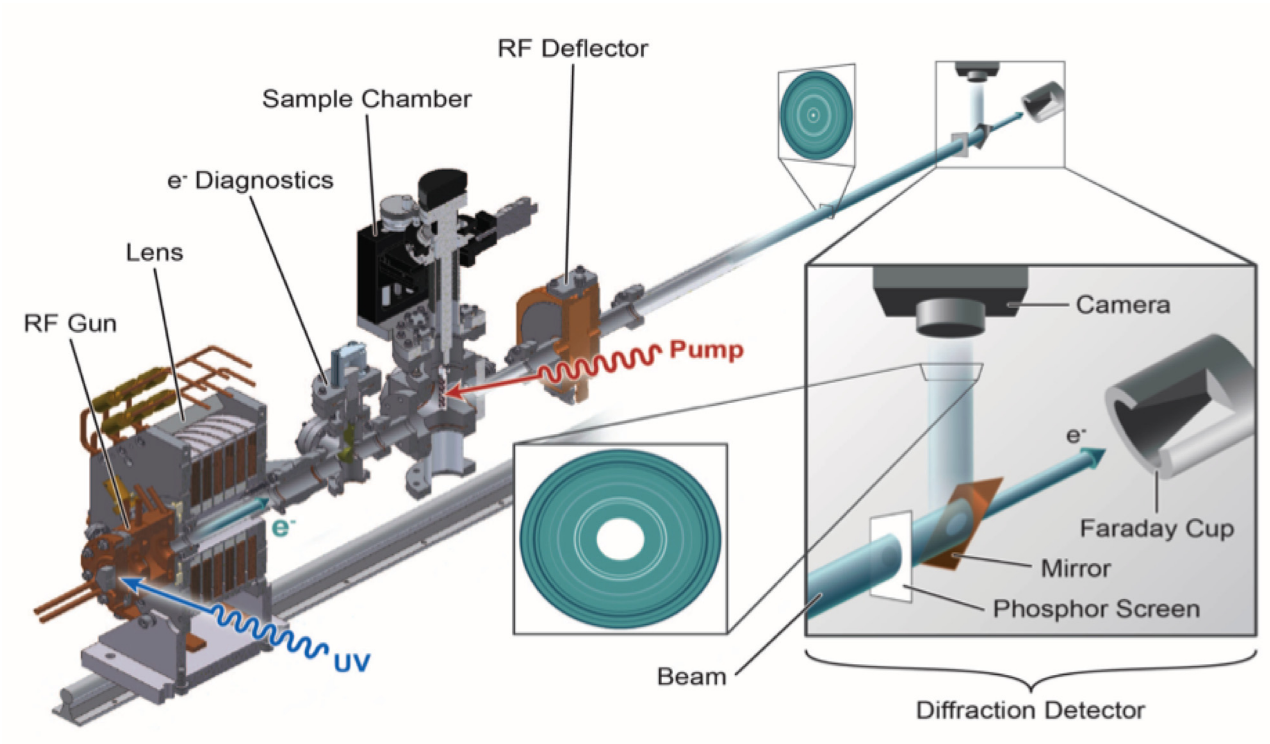

Figure 2: The layout of the initial operational configuration of the UED apparatus in Building 912 at Brookhaven National Laboratory.

- March 2016: The RF system was commissioned and conditioned to full power. The control system was also commissioned.
- April 2016: Conducted a facility readiness review and began laser system commissioning.
- May 2016: Authorization received to begin beam commissioning.
- June 2016: First diffraction pattern observed,
- February 2017: Operational beam parameters was achieved for routine diffraction measurements as shown on Figure 3.
- March 2017: Electron beam was synchronized with pump laser Figure 4.

After observation of the first diffraction pattern from the device in June 2016, 3 months of facility tune-up and refinement followed. During this time, a number of issues were addressed including improvements to the temperature and humidity control in the facility, an evaluation of beam stability issues, and general preparations for the transition to user operations.

An important feature of Figure 1 is that the layout of the UED in its new location provides considerable space for further development and extension of the beam line. This space will, for instance, accommodate a bunch compressor to provide shorter electron bunches for the diffraction measurements. In general, this space provides flexibility for deploying developmental additions to the instrument as part of the accelerator experimental program.

Details of the UED apparatus are shown in Figure 2. The operating beam energy is obtained directly from the 1.6-cell photocathode gun operating at an RF frequency of 2.856 MHz. The photocathode is driven by a Ti-Sapphire laser system with 160 fs pulse length. This laser system also provides pulses to support the experimental measurement system. Typical operations are carried out with 2.8 MeV beams with a bunch charge of ~1 pC at a repetition rate of 1 Hz. The beamline contains diagnostics to optimize and characterize the beam and we anticipate expanding the available measurement capabilities as the beamline is upgraded. Figure 4 shows the sample holder that is used to hold the samples under study. It is designed to accommodate multiple samples simultaneously so that the experimenters can work efficiently. The sample holder can be cooled to cryogenic temperatures, as necessary, for the experiments being conducted.

EXPERIMENTAL PROGRAM FOR THE UED FACILITY

Operations at the UED facility will be an integral part of the ATF National User Facility experimental program. As such, work at the facility will be allocated time through our standard ATF proposal process where all proposals are evaluated by the ATF Program Advisory Committee.

At present, two types of proposals are being accepted for the facility. The first category is for accelerator R&D to further advance UED and UEM capabilities. Clearly,

Copyright © 2017 CC-BY-3.0 and by the respective authors

ISBN 978-3-95450-182-3

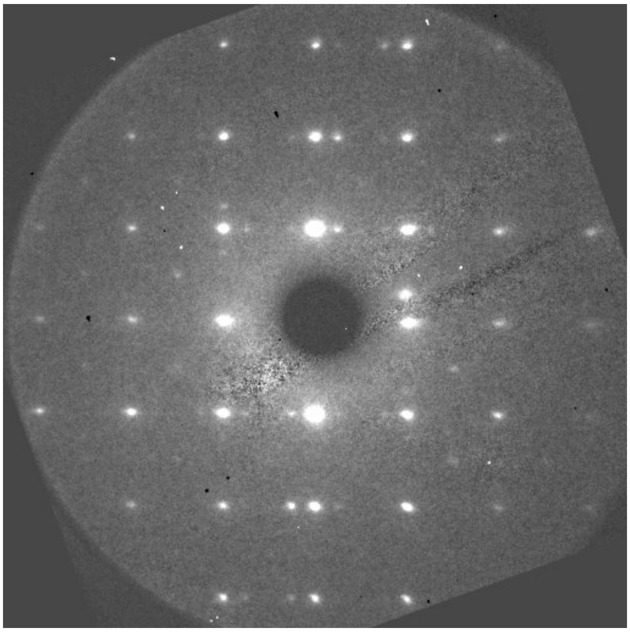

Figure 3: Present operational diffraction pattern (March 2017). Superscstructure spots can be observed around main peaks.

proposals of this type are fully aligned with ATF's role to advance accelerator science and technology. The second category of proposals being accepted comes from the material science community - these proposals aim to take advantage of the UED accelerator capabilities as they are being developed and to characterize the progress being made in improving the facility's performance. In order to support these research efforts, which go beyond the expertise of our ATF operations team, we are partnering with our BNL colleagues from the Energy and Photon Sciences Directorate to provide experimental and technical support for users of the facility's experimental station. The agreements and procedures being put in place to provide this support are similar in all respects to the procedures utilized by many of the US light sources for "partner x-ray beamlines", which are co-developed by the facility and an outside organization or collaboration.

An overarching goal for US fiscal year 2017 is to bring the UED facility into smooth operation as part of the ATF portfolio. This involves not only maintaining stable operation of the facility, but also establishing the full range of user procedures and support mechanisms required to ensure good scientific output from this instrument. Thus, FY17 will be a transitional year for the facility as we integrate it with the overall ATF research program.

CONCLUSION

US FY 2017 represents a number of firsts for the ATF team. The UED facility has now been commissioned and is transitioning to user operations as part of the ATF. It also represents the first element of the ATF-II facility portfolio to become operational. For the ATF operations team, this is also the start of user operations in a new location in BNL Building 912. We are also looking forward to supporting the first of many interesting research proposals utilizing the UED over the course of the next year.

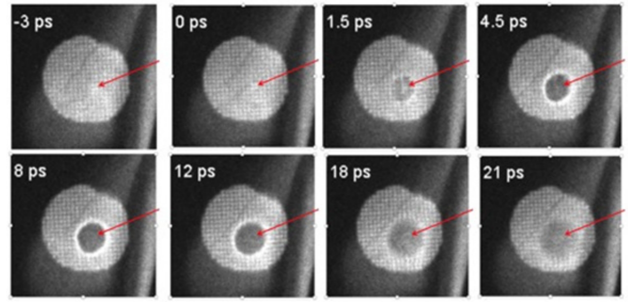

Figure 4: Electron beam image of the copper grid profile with imposed laser pump spot in it at different time.

ACKNOWLEDGMENTS

We would like to acknowledge the support of the management teams of both the BNL Energy & Photon Sciences Directorate and the Nuclear & Particle Physics Directorate in executing the relocation and re-commissioning of the UED facility. Furthermore, we would like to acknowledge the program managers in the DOE Offices of Basic Energy Sciences and High Energy Physics who supported the addition of the UED to the ATF-II research portfolio. Finally, we would especially like to acknowledge the BNL team, led by X.J. Wang that originally developed the UED system that is presently integrated into the ATF-II.

REFERENCES

[1] I.V. Pogorelsky, I. Ben-Zvi, M.A. Palmer, "Fulfilling the Mission of the Brookhaven ATF as DOE's Flagship User Facility in Accelerator Stewardship", presented at NAPAC16, Chicago, IL, October 2016, paper THB2IO03.

[2] P. Zhu *et al.*, "Femtosecond time-resolved MeV electron diffraction", *New J. Phys.*, vol. 17, p. 063004, 2015.

[3] M. Chergui and A. H. Zewail, "Electron and X-Ray Methods of Ultrafast Structural Dynamics: Advances and Applications", *ChemPhysChem*, vol. 10, pp. 28–43, 2009.

[4] R.J.D. Miller, "Femtosecond Crystallography with Ultrabright Electrons and X-rays: Capturing Chemistry in Action", *Science*, vol. 343, Issue 6175, pp. 1108-1116, 2014.

[5] X. Wang *et al.*, "Measurement of femtosecond electron pulse length and the temporal broadening due to space charge", *Rev. Sci. Instrum.*, vol. 80, p. 013902, 2009.

Copyright © 2017 CC-BY-3.0 and by the respective authors